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| In the Matter of | ) | |
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| Replacement of Part 90 by | ) | |
| Part 88 to Revise the Private | ) | PR Docket 92-235 |
| Land Mobile Radio Services | ) | |
| and Modify the Policies | ) | |
| Governing Them | ) | |

**REPLY COMMENTS OF SECURICOR PMR SYSTEMS LTD.**

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## REPLY COMMENTS OF SECURICOR PMR SYSTEMS LTD.

Securicor PMR Systems Ltd. ("Securicor PMR"), by its counsel, hereby submits its Reply Comments on the Notice of Proposed Rule Making ("NPRM") in the above-captioned proceeding.[1] Over 400 parties, including Securicor PMR, filed Comments on the Commission's proposal to replace Part 90 of its Rules governing the Private Land Mobile Radio ("PLMR") Services with new Part 88, and to implement policies promoting the "refarming" of the PLMR bands below 512 MHz to increase the efficiency of usage of those bands.

As stated in its Comments, Securicor PMR believes that the United Kingdom's experience looking toward the establishment of standards and rules to govern the migration of U.K. land mobile radio ("PMR") systems from their existing 12.5 kHz channelization to very narrowband ("VNBR") 5 kHz channelization can be

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[1] Replacement of Part 90 by Part 88 to Revise the Private Land Mobile Radio Services and Modify the Policies Governing Them, 7 FCC Rcd. 8105 (1992).

most useful to the Commission in its parallel effort as reflected in this proceeding.[2] For instance, the Comments generally reflect disparate views regarding the appropriate pace for the transition to narrower channelization[3]. Faced with a similar situation, the U.K. has adopted a general policy whereby it provides PMR licensees two years prior notice of all changes to technical standards and a further five years for implementation of those changes. Although licensees are required to accept this policy as a condition of licensing, both licensees and equipment providers have

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[2]As explained in its Comments, Securicor PMR provides and operates trunked private mobile radio systems throughout the U.K. For many years, Securicor PMR has fulfilled the internal land mobile communications needs of its parent's (Securicor Group, plc) large parcel delivery, cash-in-transit, security service and other fleets, and has been an active proponent of the development of emerging spectrally-efficient very narrowband ("VNBR") land mobile technologies. In this regard, Securicor PMR's affiliated company, Linear Mobile Technology Ltd., has developed for commercial deployment the Linear Modulation, or "LM," 5 kHz PMR system that was described by Peter Hilton, Managing Director of Securicor PMR, during the FCC's May 6, 1993 roundtable discussion on the refarming initiative and discussed in detail in Securicor PMR's Comments. Since that time, Securicor PMR has embarked on a program to ensure the manufacturing and distribution of LM technology throughout the United States, having entered into agreements and/or reached understandings with CYCOMM Corp. and E.F. Johnson for these purposes. These recent developments support the statements made in Securicor PMR's Comments that 5 kHz VNBR is here today, and that Securicor PMR is committed to its rapid deployment.

[3]As examples of comments favoring a slower paced transition, see the Comments of the Alarm Industry Communications Committee, pp. 4-7; Comments of the Telecommunications Industry Association, pp. 3-6; and the Comments of Utilities Telecommunications Council, pp. 32-36. Examples of Comments favoring a more rapid, or a one-step, transition include the Comments of Nippon Telegraph and Telephone Corporation, pp 7-9; Comments of SEA Inc., pp. 15-19; and the Comments of Airborne Express, p.2.

embraced the policy as an equitable balancing of the competing demands of spectrum efficiency and equipment cost amortization.[4]

Before clarifying certain technical aspects of LM technology, and reporting on the results of new testing, Securicor PMR would like to correct an erroneous statement contained in the comments of GEC-Marconi Communications Limited ("GEC-Marconi")[5] and place their comments in the proper context. Specifically, the comments state in section 2.5 Modulation Methods that "SSB [single sideband] requires much larger reuse factors than FM," citing as support a paper published by Prabhu & Steele.[6] It must be understood, however, that the principal object of the Prabhu and Steele paper was to present the advantages that might result from the application of frequency hopping to SSB, not to compare the relative spectrum efficiencies of SSB and FM technologies, either theoretically or

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[4]Securicor PMR understands that Canada has adopted a similar transition policy. See "Spectrum and Orbit Policy Directorate," Section 3.4, Telecommunications Policy Branch, Spectrum Utilization Policy, Department of Communications, Government of Canada (January, 1991).

[5]GEC-Marconi's submission in this proceeding is a document entitled "Private Land Mobile Radio Migration to Narrowband Channels," dated April 27, 1993.

[6]V.K. Prabhu and R. Steele, "Frequency Hopped Single Sideband Modulation for [redacted]

empirically.[7] Accordingly, as explained below, the paper's applicability in the present context is extremely limited.

First, given its stated objective, the Prabhu and Steele paper is wholly irrelevant to any debate on the relative merits of non-hopping LM, FM or TDMA systems. Second, since the time of the paper's publication over ten years ago,[8] SSB technology has advanced to the point where the SSB technology analyzed in the paper is far different than, and inferior to, today's technology. For example, the authors of the paper state that the SSB systems that they considered used a pilot tone which has a frequency fp "selected to reside outside the bandwidth Bc of the SSB signal" (Prabhu and Steele, p. 1395). The paper, therefore, applies only to tone-above-band (or tone-below-band) systems which are known to have radically different and inferior properties to the Transparent-Tone-In-Band (TTIB) system used by Securicor PMR in its LM system.

Finally, the paper has been repudiated by further practical work performed by the Bristol and Bradford Universities in the U.K. and Securicor PMR. For example, attached as Appendix 4 to Securicor PMR's Comments in this proceeding is a copy of a Report of the Radiocommunications Agency ("RA") of

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[7]Indeed, in its final paragraph, the paper explicitly declines to come to a conclusion on the subject of relative spectrum efficiencies. Moreover, the paper is purely theoretical and does not present any experimental evidence.

[8]GEC-Marconi incorrectly states that the Prabhu and Steele paper was published in 1992 when, in fact, it was published in 1982. GEC-Marconi Comments, p. 15.

the U.K.'s Department of Trade and Industry ("DTI") prepared on behalf of the RA by Bradford University (the "Bradford Report"). The Bradford Report, among other things, concluded that the performance of the tested LM-SSB equipment compared very favorably to FM and AM.[9]

GEC-Marconi's attempt to use the Paper in support of an argument that SSB 5kHz LM technology may result in "illusory" gains in spectrum efficiency[10] is particularly unfounded in light of the published facts proving that LM has considerable gains over 12.5kHz FM systems in both co-channel and adjacent channel performance, and its spectrum efficiency is now beyond question. Specifically, the spectrum efficiency of LM technology is fully demonstrated in the September 1992 Report prepared by the Kenley Radio Technology Laboratory on "Linear Modulation Co-Channel Compatibility Study" (the "Kenley Report") on behalf of the RA.[11]

**LM INTERFERENCE**

In June, 1993, Securicor PMR conducted additional trials of co-channel and adjacent channel interference levels of LM on 12.5 kHz FM. The

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[9]Bradford Report, p. 5-1.

[10]GEC-Marconi Comments, p. 6.

[11] The Kenley Report was submitted to the Commission as Appendix 3 to Securicor's Comments. The Report reflects the co-channel testing of developmental 5 kHz LM equipment to establish the rules for re-farming U.K. PMR congested bands by using 5 kHz channeling.

tests, which are continuing, are intended to prove the viability of the co-habitation of LM in the FM environment. The results to date demonstrate a considerably higher level of performance than expected.[12] Specifically, the results conclusively demonstrate that LM creates less interference than FM. In a 12.5 kHz channel, 2 LM channels can be used at the band edges with their pilot tones 2.5 kHz in from the band edge. These LM channels can have a signal in the region of 12-14 dB **higher** than the centered FM signal for the same interference level as a co-channel FM signal 12 dB **down** on the desired FM signal (using standard 14 dB SINAD tests). Securicor PMR will provide the Commission with documented final test results as soon as they become available.

**<u>LM / FM PERFORMANCE</u>**

As further evidence of the relative performance of LM 5 kHz technology versus FM 12.5 kHz technology, Securicor PMR has attached as Appendix A to these Reply Comments a paper written by Professor William Gosling of the University of Bath, U.K., entitled "Comparison of the Characteristics of LM and FM Transmissions in the PMR Service," dated June 10, 1993 ("Gosling

[12]Securicor PMR has already submitted as Appendix 4 to its Comments an August 1990 "Report On the Relative Performance of Linear Modulation (TTIB-SSB) Compared to FM and AM Modulation, With Particular Reference to Interference Performance" prepared on behalf of the RA by Bradford, England University (the "Bradford Report"). The Bradford Report concluded, among other things, that "LM-SSB will provide an effective mechanism for relieving the spectral congestion currently experienced in the PMR system, while causing little disruption to the existing PMR infrastructure." Bradford Report at 5-1 and 5-3.

Paper"). After comparing LM and FM in the areas of frequency reuse and ignition interference, Professor Gosling concludes that:

> with growing spectrum congestion and the fall in hardware costs consequent upon the introduction of microelectronics, FM is certain to be replaced (over time) by more sophisticated digital systems such as LM, TDMA, or just possibly CDMA. Because LM can operate in the analogue mode if required, and has demonstrated the ability to co-exist in the same bands as existing FM transmissions, it appears to have advantages in the transitional phase. Gosling Paper, p. 5.

When comparing LM to FM it is important to remember that many "rule of thumb" calculations developed over the years for FM systems are not applicable to LM systems. For example, one of the most difficult of the LM phenomena to grasp is its ability to exist in between two adjacent channels, thereby creating a new channel that overlaps portions of the adjacent channels without causing harmful interference.[13] The effect of this phenomenon is to enable closer geographical spacing of the same channel, giving a reuse factor approximately 4-5 times greater than 12.5 kHz FM. This feature of LM can only serve the interest of mobile radio users as well as the Commission, inasmuch as additional frequency assignments will be greatly facilitated.

**DATA EFFICIENCY**

Data transmission efficiency has been used as a measure of spectrum efficiency. The LM 5 kHz solution currently offers an efficiency of 1.92 b/s/Hz

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[13] See Kenley Report for co-channel performance at 2.5 kHz offsets.

compared with the stated objective of 1.28 b/s/Hz. Although some commenters have questioned the ability of narrowband channels to transmit high speed data,[14] Securicor PMR is continuing its development of data transmission speed and sees a realistic feasibility of achieving 19.2 kb/s in high signal strength areas with automatic reductions for weak signal areas. Such speeds would result in spectrum efficiencies in the order of 3.8 b/s/Hz. Although these are obviously raw data speeds, when the order of reduction in bit-error-rates provided by LM is taken into account, the real efficiency improvements are dramatic.[15]

**POWER / HEIGHT REDUCTIONS**

In their comments, many existing users have expressed the concern that transmitter power and antenna height reductions will require the use of a greater number of transmitter sites to provide the same coverage in a given area.[16] This concern, however, fails to recognize that what drives the need for reduced height and power is the equipment itself, not arbitrary regulatory forces. Newer types of systems that employ trunking and frequency reuse inherently require

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[14] See, e.g., Comments of American Meter Company, pp. 4-7.

[15] See, e.g., Gosling Paper, p.4 ("All in all, the superiority of LM over FM for mobile data transmission seems clear and indisputable").

[16] See, e.g., Comments of the Alarm Industry Communications Committee, pp. 24-27; Comments of the State of Alaska Division of Information Service Telecommunications Section, p. 3; Comments of Metro-North Commuter Railroad, p. 2; Comments of the Utilities Telecommunications Council, pp. 40-46; Comments of the Commonwealth of Virginia, Department of Health, Office of Emergency Services, pp. 18-20.

lower power and height in order to operate efficiently. Thus, if new equipment is introduced at all, power and height reductions will necessarily occur.

Existing users also generally share the misconception that power in larger quantities equates to greater range. This is another example of a situation where the "rules of thumb" for FM do not wholly apply to new LM technology. LM offers an improved range/power curve of 3-6dB over FM, with the range edge performance exhibiting a much more graceful degradation.

The U.K. experience of the last decade shows that the old PLMR orthodoxy can be overcome by showing the efficiencies and other benefits of the latest trunking systems. As stated in its Comments, Securicor concurs with the Commission in its desire to forge this route to increased spectrum efficiency, but also recognizes that some relaxation of lower power and height restrictions may be acceptable and necessary in very rural areas.[17]

## CONCLUSION

Securicor PMR has sought in its Comments and Reply Comments to emphasize that 5 kHz VNBR technology is here today, that it can peacefully co-habit with existing FM systems, that it performs significantly better and is more spectrally efficient than FM technology. In further support of this belief, Securicor PMR is prepared to offer a challenge to compare any other technology with LM to

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[17]See, e.g., Comments of the State of Alaska Division of Information Service Telecommunications Section, p. 3.

prove its superior co-channel, adjacent channel and raw data transmission speed performance characteristics. Accordingly, Securicor PMR submits that the Commission can proceed directly to a 5 kHz channelization plan, rather than an interim 12.5 kHz plan, with great confidence that the needs of the land mobile community will be satisfied for some time to come.

Respectfully submitted,

**SECURICOR PMR SYSTEMS LTD.**

By: ______________________

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July 30, 1993

# APPENDIX A

# Comparison of the characteristics of LM and FM transmissions in the PMR service

*Prof. William Gosling*
*University of Bath*

## 1. Introduction

Interest in the use of linear modulation (LM) techniques in the land mobile service began in the late 1960s, in those days concentrated on analogue voice single-sideband transmission. Practical systems were demonstrated in a number of centres during the 1970s and 80s[1,2,3], but until recently the hardware technologies available were such that equipment could not be introduced into the very cost-sensitive PMR market at a sufficiently competitive price to achieve wide acceptance. The major historical advantage of FM, with its constant amplitude PAs operating in Class C and simple limiter/discriminator receivers, has been exceptionally low equipment cost, and this has understandably led to its widespread adoption. However now that digital signal processing technology is well established a new generation of LM equipment, for both analogue and digital signals, has become available at competitive cost, and the issue as to whether it is therefore time for FM to give way to more sophisticated modulation systems naturally presents itself. The question is complicated by the parallel development of TDMA systems, which also show much promise, but that issue will not be touched on here.

With the arrival of cost-effective LM equipment, the relative system merits of FM and LM are now being debated once again, as they were twenty years ago[4]. Indeed it would seem that with the passage of time much of the earlier literature on the subject has been forgotten, because erroneous arguments, long ago disposed of[5], are being presented once more. The mistakes of an earlier epoch were excusable because, at the time, there was little evidence available from field or laboratory experimentation, however that is no longer the case, and there is now a wealth of incontrovertible and objective evidence. It is no longer necessary to rely upon risky arguments from over-simplified theory, therefore, which in the past were often made to yield quite different conclusions, depending on the starting assumptions of those who deployed them.

In fact it is now well understood that the difference in the characteristics of FM and LM systems presents no mystery once the nature of the radiated signals and the underlying physics of propagation in the mobile environment are properly considered. In what follows these arguments will be summarised. Extensive experimental results and field trials confirm the conclusions beyond serious doubt.[6,7]

## 2. Frequency re-use in the land mobile environment

The essence of the argument between the systems turns on the distance at which a frequency can be re-used, chosen to ensure that the near edge of the next service area is at or beyond the limit of the effective interference range. The proponents of FM have always sought to argue that although LM could be engineered into narrower channels the apparent saving in spectrum would be offset by the larger frequency re-use distance, as a consequence of losing the capture effect expected in FM transmissions. Incidentally the

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[1] Wells R. 'SSB for VHF mobile at 5kHz channel spacing.' *Proc. Conf. Radio Receivers & Associated Systems*, IERE London, 1978.

[2] Lusignan, B. B. 'AGC, AFC, tone select circuits for narrow-band mobile radio' *Intelcom 79*, Dallas, 1979

[3] Gosling, W. McGeehan, J. P. and Richardson, J. H. 'The Wolfson SSB land mobile radio system.' *3rd World Telecommunication Forum*, Pt. II, ITU Geneva, 1979.

[4] Muilwijk, D. 'Comparison and optimisation of multiplexing and modulation methods' *Philips Res. Repts.* Vol. 28, 1973.

[5] Gosling, W. 'Protection ratio and economy of spectrum use in land mobile radio' *Proc. IEE*, Vol. 127, Pt. F, 1980.

[6] Mc Geehan, J. P. 'The case for using 5 kHz ACSSB in Band III' IEE Colloquium on *Communications Systems for Band III* , UK, 1984.

[7] ——— 'Linear Modulation Co-Channel Compatibility Study' *Kenley Radio Tech. Lab.* Project 148, 1992.

same argument had previously been used, particularly in the United States[8], in an attempt to demonstrate that no economies of frequency use would be achieved by reducing FM channel widths from 25 (or 30) to 15 or 12.5kHz, but that view did not prevail.

In order to pursue the frequency re-use argument further it is necessary to consider the nature of the transmitted signal. This depends both on the system of modulation chosen and also on whether it is analogue voice or digital data (including digital voice) which is being carried.

**2.1 The case when analogue voice is being carried**

For both full-carrier AM and NBFM analogue voice transmissions the majority of the power transmitted is in the form of carrier. This is made worse because of the impossibility of achieving consistently 100% modulation. The dynamic range of a radio operator's voice (excluding person to person variations) is typically 25dB, although this can be reduced by compression or clipping, at the cost of some distortion. Because modulation must not exceed 100% on peaks of speech power it is common to sustain an average modulation index of little better than 30%, even with moderate speech processing. On this basis, average sideband power is only 4.5% of carrier (-13.5dB), and even with 60% average modulation, which can only be sustained by severe speech processing, this only rises to 18% (-7dB). AM and NBFM differ little in this respect, since if only the first pair of sidebands is present they are distinguished merely by the phase relationship of carrier and sidebands.

However this is average power during utterances, and since silences between utterances are up to half the transmission time, it will be seen that on average 90% or more of the radio frequency energy transmitted is carrier. In consequence it is carrier-carrier interactions which dominate mobile radio co-channel interference in AM or FM systems.

Since frequency re-use distance is simply a function of protection ratio, assuming the same conditions of propagation, it is evident that frequencies may be re-used at comparable or shorter distances using LM than with FM systems. In practice, however, frequencies must be assigned in certain fixed, discrete patterns and the advantage of LM is not sufficient to reach the next lower assignment plan. It will therefore manifest itself primarily as a small improvement in signal-to-interference ratio at the edge of the coverage area, and the overall advantage of simple LM systems in spectrum utilisation remains the 2.5:1 dictated by the relative channel widths.

## 2.2 FM capture effect

It is evident from public statements on this topic that it is not well understood, and therefore a few words of clarification may be appropriate. Like many non-linear systems FM manifests a threshold effect. When two signals are presented to an FM demodulator which differ in magnitude by more than the threshold value, the ratio of the wanted to interfering signal amplitudes after demodulation is greater than that before, so that the wanted signal is heard but the unwanted is, to some degree, suppressed.

This is a useful characteristic of FM in situations, such as point-to-point links, where the two signals are relatively well-defined and constant. It also helps to improve the demodulated signal-to-noise ratio, provided that the wanted signal is well above the threshold. However the effect is very dependant on the extent of frequency deviation, and for this reason is less marked in 12.5kHz NBFM systems compared with systems using wider deviation. It is precisely this argument which was at one time unsuccessfully deployed in favour of the retention of 25kHz channels.

Many published measurements of such things as protection ratio overlook the under-modulation of FM transmitters carrying analogue voice; the results claimed are quite often valid only at full modulation A figure of around 10dB is sometimes quoted as the (first) threshold for FM in 12.5kHz channels, however this is a measured value with sinusoidal modulation at constant deviation and bears little relationship to what happens in analogue speech transmissions. As already indicated, during the roughly half of the total time when it is modulated at all, the transmission will do well to average much more than 30% modulation depth, with 60% average as something like a practical limit. Thus the capture effect is varying rapidly during speech transmissions and is mostly considerably weaker than the laboratory figure quoted, corresponding to a higher threshold. This varying threshold through the speech utterance is perceived as distortion when signal strength is low and is one of the reasons for the loss of speech quality in FM systems under co-channel interference conditions, the other being defective demodulation.

However even if it were reliably present, it is not clear how much of an advantage capture effect would be in the land mobile service under consideration, particularly in the case of a moving user. As is well known, mobile radio signals received by scattering propagation have amplitudes which are Rayleigh distributed and deep fades are frequent. When an FM signal falls below the threshold (which may be high at low modulation indices) the output SINAD ratio rapidly falls to zero, producing a sudden and audibly disturbing 'chopping' of the signal, a phenomenon able to destroy the intelligibility of speech if it recurs at or near the syllabic rate in a moving vehicle. Each loss of signal in fades is accompanied by audio distortion as the demodulation process collapses. By contrast an LM signal, having no threshold, fades and returns smoothly with much less audible impact and without demodulation failure in correctly designed equipments; it is for this reason that LM is sometimes said to possess the property of graceful degradation.

When a co-channel interfering signal is present, Rayleigh fading of the two signals is not correlated, due to the large spatial separation between the originating transmitters. Thus the wanted signal will, in general, go through deep fades in the presence of a strong interfering signal, and with capture effect the result is a sharp 'switch' from the former to the latter accompanied by severe distortion during the process of transition. However in other than the case of very slowly moving vehicles, the fade is transient so that the predominant auditory effect is a burst of distortion and the content of the interfering signal may not be recognised as such. The principal difference in the case of two LM signals is that due to the nature of the demodulation process the distortion at transitions is not present with LM; in a Rayleigh fade the wanted signal briefly weakens and a short segment of an interfering signal may be heard, which, depending on vehicle speed, will usually be too brief to be identified.

By contrast, for mobiles in strong signal areas the threshold effect of FM can give a useful increase in demodulated SINAD ratio compared with a linear system of similar bandwidth, since the signal rarely falls below the threshold. However note also that the total noise power delivered to the demodulator in a 5 kHz LM system is about 4dB lower than in a 12.5 kHz FM system, due to the difference in bandwidth, and in addition the available reduction in LM transmitter output power (due to carrier suppression) is often exploited actually to radiate more sideband power than in the FM case, which may just about balance things out. Since the SINAD ratio is high in these areas anyway a decibel or so of advantage, whichever way it happens to fall, is not likely to be significant.

In the case of hand-held equipment or a stationary user, the Rayleigh distribution no longer predicts the time-dependant signal variation in a particular mobile but must be interpreted as giving the probability of finding an acceptable signal at a particular location. Users who are able to change their position at will should be able to avoid operating in a deep Rayleigh fade. Most operators simply try a number of locations until a good enough signal is found. Once this is located both FM and LM systems should perform well.

### 2.3 Data transmission

When data is being transmitted the FM modulation index is virtually constant and can be made much larger than the average value for voice, usually in excess of 90%, thus capture effect is real and significant. However in LM systems virtually all modems encode data as two or more levels of phase or frequency modulation, envelope shaping being used primarily to give a favourable and well-constrained radiated RF spectrum, thus LM is also an angle modulated data system and demonstrates threshold and capture effects which are different only in minor aspects from those with FM. In this respect there is little to choose between them, therefore, and closely similar patterns of frequency re-use can be expected.

The main points of difference between FM and LM are therefore:

i. LM radiates no carrier and therefore causes less spectrum pollution.

ii. LM occupies a narrower bandwidth than FM in the ratio 2.5:1, and hence (a) more users can be accommodated and (b) 4dB less white noise is passed by the receiver filters, with a correspondingly lower contribution to bit error rate from this cause.

iii. Modern 5kHz LM systems use sophisticated means for compensating channel impairments (such as FFSR), and therefore can transmit data at 9.6kb/s with raw bit error rates in an urban environment in the range $10^{-3}$ to $10^{-4}$, as against $10^{-2}$ to $10^{-3}$ at 4.8kb/s for good FM systems.

The last point is a somewhat unfair comparison. In the LM system FFSR (feed-forward signal regeneration) is really a form of equalisation, and if the FM system were fitted with a suitable equaliser its transmission rate would presumably be improved. However FM would then partly lose its sole advantage, which is its low-cost, simple hardware. All in all, the superiority of LM over FM for mobile data transmission seems clear and indisputable. Needless to say, the same would be true in the case of digital speech transmissions.

## 3.0 Ignition interference

Although ignition interference causes somewhat less concern than formerly, due to improvements in vehicles, for the sake of completeness this topic will be briefly reviewed. A quarter of a century ago, proponents of FM, which was then in 25 or 30kHz channels, attempted to promote the view that ignition noise effects would be more serious in 5kHz systems[9]. The argument used then assumed that noise could be well approximated as impulses of near-zero duration and infinite, or very large, amplitude. In this case, to a first order the post-IF amplitude of the noise pulse can be shown to be dependent only on limiting in the receiver, while its duration would be inversely proportional to the IF filter bandwidth, thus the total pulse energy might be five times greater in a 5kHz system than in

[9] Beusing, R. T. 'Modulation methods and channel separation in the land mobile service.' *IEEE Trans. Vehic. Tech.* Vol. VT19, 1970.

25kHz. Psychoacoustically, the noise pulse event is perceived as without discernable duration, because it is short compared with 30 milliseconds (de Haas effect), and the subjective impression will therefore correlate well with total energy.

The flaw in this proposition lies in the assumption that all pulses would be of infinite amplitude. In reality ignition pulse amplitudes have a statistical distribution, so that although a few are indeed large, many do not drive the IF into limiting. Since the total noise pulse power admitted by the narrow band filters is 7dB less than that for 25kHz channelled systems, it is even more likely in LM systems that the IF will not limit. If limiting does not occur, the amplitude and total energy of noise pulses is correspondingly less in the narrow band system, even although their duration is indeed longer, although still well under the de Haas limit. Experimental trials at the time[10] amply confirmed that 5kHz systems were indeed less susceptible to ignition interference than the best FM systems then available, in either 12.5 or 25kHz channels.

In the intervening decades there has been a substantial improvement in the suppression of ignition interference from vehicles, and the number of significant interferers has greatly reduced. In consequence the mean distance to the most proximate interferer has increased and the probability of ignition pulses large enough to cause IF limiting is reduced still further. The advantage for narrow band systems has become more marked and ignition interference, although hardly a major issue any longer, favours LM over FM.

## 4.0 Conclusions

Careful examination of all the scientific facts bearing on the comparison of 12.5kHz FM and 5kHz LM systems in the PMR service will lead, I believe, to the following conclusions:

i. There will be no significant difference in frequency re-use distance between the two systems if normal frequency assignment patterns are used.

ii. The improvement in spectrum economy achieved will therefore not be less than the 2.5:1 ratio of the channel widths[11].

iii. LM causes less spectrum pollution than FM because no carriers are radiated.

iv. The advantage of LM over present FM systems is substantial for data or digital speech transmission.

v. In analogue voice service, FM is capable of giving good results in areas where the signal strength is reliably above the threshold, but it deteriorates in marginal areas, under conditions of Rayleigh fading and co-channel interference, where the degradation of the performance of LM systems is more gradual.

In the PMR service, analogue FM is a 'cheap and cheerful' radio system characterised by low hardware costs and excellent performance in strong signal areas, but also by noisy and distorted fringe-area working and poor utilisation of the electromagnetic spectrum. It has played an important historical role in helping to develop the service to its present stage, and is not quite yet at the end of its useful life. Even so, with growing spectrum congestion and the fall in hardware costs consequent upon the introduction of microelectronics, FM is certain to be replaced (over time) by more sophisticated digital systems, such as LM, TDMA, or just possibly CDMA. Because LM can also operate in the analogue mode if required, and has demonstrated the ability to co-exist in the same bands as existing FM transmissions, it appears to have advantages in the transitional phase.

*10th of June 1993*

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[10] Gosling, McGeehan & Richardson, *op. cit.*

[11] It has been argued by its proponents that LM can do better than this by exploiting its special characteristics, such as half channel offsets and different assignment of pilot tones, but no attempt has been made here to evaluate the advantages to which such possibilities give rise.

## CERTIFICATE OF SERVICE

I, Douglas L. Povich, hereby certify that on this 30th day of July, 1993, copies of the foregoing Reply Comments of Securicor PMR Systems, Ltd. were sent by first class mail, postage prepaid, to the following parties:

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